

FLASH RADIOGRAPHIC STUDIES OF
HYPERVELOCITY PROJECTILE INTERACTIONS
WITH EXPLOSIVES

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T. J. BUSSELL AND M. C. CHICK

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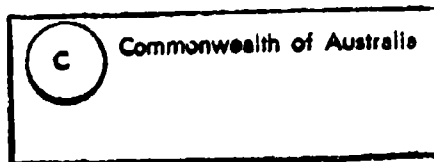


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Flash Radiographic Studies of Hypervelocity Projectile Interactions with Explosives

T.J. Bussell and M.C. Chick

MRL Technical Report
MRL-TR-91-51

Abstract

This report describes multiple, flash radiographic techniques developed in an investigation aimed at understanding and predicting the processes which occur when a hypervelocity projectile interacts with explosive filled ordnance. Hypervelocity projectiles were generated by shaped charges and characterized by multiple flash radiography. Explosive/metal target assemblies were designed to be representative of various aspects of explosive filled ordnance or components.

The techniques have been used to study the projectile impact on bare explosive, penetration through covers into explosive, the supersonic projectile penetration of the explosive and the evolving structure of the bow wave shock that forms several millimetres in front of the projectile tip, the onset and progress of detonation both forward and backward in the explosive and the relative contribution of spall and jets in behind-the-plate initiation of explosives.

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Tim Bussell studied at the Royal Melbourne Institute of Technology, graduating BAppSc (with Distinction) in Applied Physics. He began work at MRL in 1982 and has been involved in the development and application of various experimental methods to study explosive phenomena. He has had several years experience with flash x-ray systems and is currently developing manganin gauge techniques for application to high pressure measurements in explosives.

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Michael Chick graduated as a Licentiate of the Royal Institute of Chemistry (1963). He has worked on explosives research and development for most of his career, commencing at the Atomic Weapons Research Establishment, UK, in 1957 and moving to Explosives Ordnance Division, MRL in 1967. During 1982/83 he was attached to Ballistic Research Laboratory, USA. He is currently concerned with investigating several different aspects of explosive effects; these include the origins of the mass detonation hazard of munitions, the interaction of high velocity metal projectiles with explosives, explosive ordnance disposal and sea mine neutralization.

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Flash Radiographic Studies of Hypervelocity Projectile Interactions with Explosives

1. Introduction

Flash radiography (flash X-ray) is an effective instrumentation technique that can be used to record ultra high speed phenomena associated with hypervelocity projectiles. One advantage of this technique is that it can be used to investigate reactions which occur inside a material, or which may be obscured by reaction products, fire, high intensity light or debris. Materials Research Laboratory (MRL) has been using flash X-ray techniques over the past 15 years to investigate various aspects of munition response and performance, and has developed several methods of optimizing the performance of the flash X-ray system.

This paper describes the basic system and explains in detail the techniques we have developed to assist in investigations of hypervelocity projectiles and their interaction with explosive materials commonly used as ordnance fillings. Several examples are described which illustrate the successful application of these techniques.

2. Facilities and Equipment

2.1 Facilities

Experiments are carried out in a firing chamber designed for a maximum 2.25 kg charge mass, equipped with 9 viewports arranged around a common centre and extending along one side wall (Figs. 1 and 2). This facility allows flexibility in geometric arrangements for various charge assemblies and provides easy access to instrumentation both inside and outside the firing chamber.

It is supported by several additional facilities established in the immediate vicinity including charge preparation bays, workshop and equipment storage facilities.



Figure 1: MRL 2.25 kg firing chamber facility.

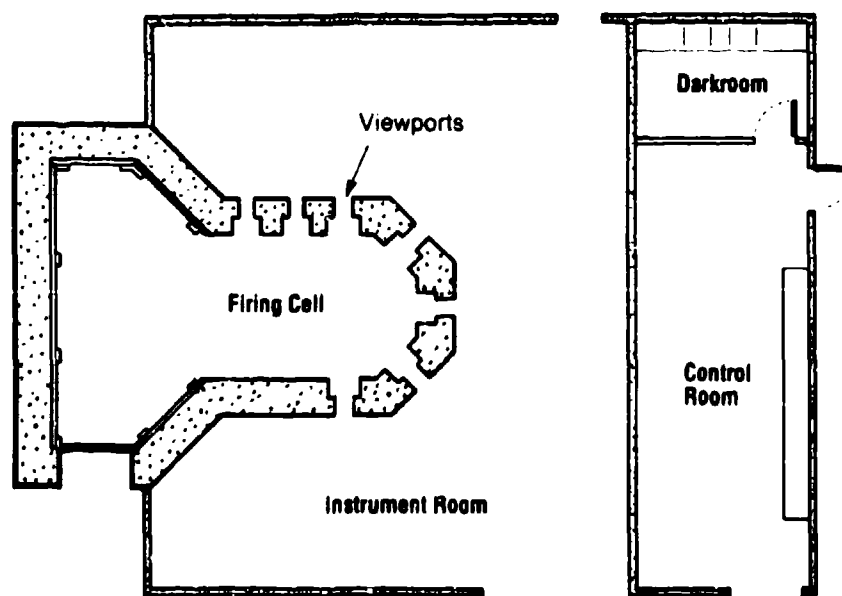


Figure 2: Layout of firing chamber facility.

2.2 Flash X-ray Equipment

The flash X-ray equipment produces a high energy X-ray pulse within the range of 150 to 600 kV for a duration of 20 to 30 ns. The intensity and speed of the pulse is sufficient to expose an image over an area of approximately 2 square metres, and freeze the motion of a projectile moving at speeds up to 30 kilometres per second.

A schematic diagram showing the arrangement of a basic two channel flash X-ray system is shown in Figure 3. The remote head positions shown are orthogonal, but this is not necessarily the case. Many other alignments are possible including down range linear arrays and stereography, depending on the test requirements.

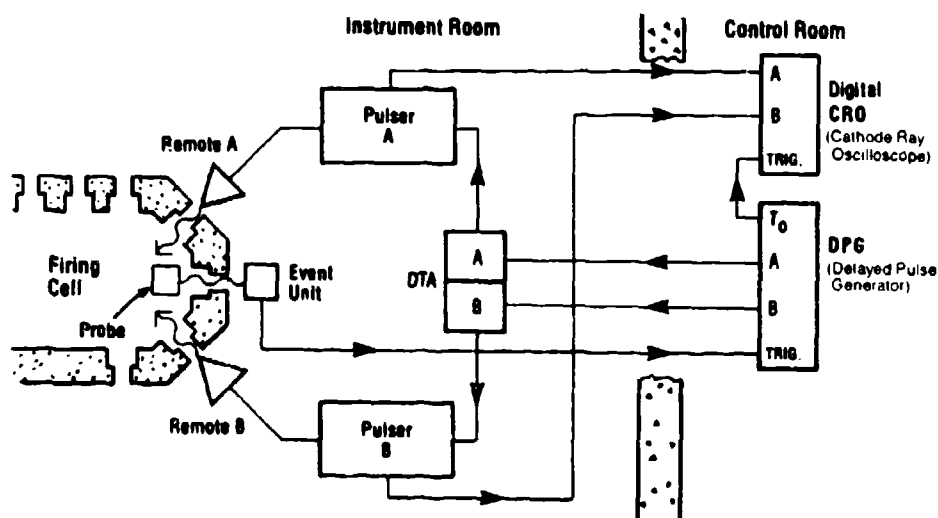


Figure 3: Flash X-ray system wiring diagram.

The MRL flash X-ray system consists of Hewlett-Packard Model 2660 600 kV and model 2710 300 kV pulsers with or without remote tubeheads. The pulsers are fired by model 43115A trigger amplifiers which are controlled by model 43114A delayed pulse generators. A full description of the operation of this system can be found in reference 1.

2.3 Electronic Probing and Triggering

The delayed pulse generator connected to the pulser trigger amplifiers generates pulses at a set interval after a reference time (t_0) to fire the pulsers. This reference time is derived from either the detonator firing pulse or from an electronic probe positioned down range or within the charge assembly. Several types of probes can be used depending on the stimulus causing it to trigger. Two different types are

shown in Figure 4. The ionization probe (Fig. 4(b)) functions when an ionized region such as that found in a detonation front, passes between two electrodes, giving rise to a conductive path between them. The laminated probe (Fig. 4(a)) is similar to the ionization probe in that when it functions it completes (makes) a circuit. However, with this probe the circuit is made by mechanically puncturing the insulating mylar or by a high pressure causing the mylar to become conductive, thereby making the circuit.

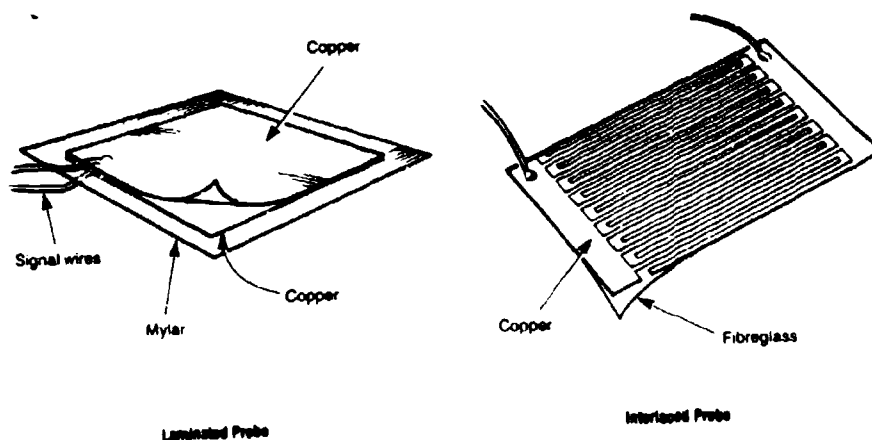


Figure 4: Electronic trigger probes (a) laminated, (b) interlaced.

Both of these probes generate a capacitor discharge spike when the circuit is made and this signal can then be used to trigger the delayed pulse generator, which in turn fires the pulsers at the required instant.

2.4 Timing Records

Digital oscilloscopes or signal digitizers are used to record the timing sequence. Usually, a general purpose oscilloscope will be sufficient where the system accurately records the time of arrival of the pulse. Electronic counters could be used, but we have found that spurious pulses which may cause erroneous triggering in counters can be identified on a CRO and discounted while the true pulse is still recorded. For this reason it is usually advisable to begin recording the time baseline as early as possible as an aid to problem diagnostics if needed. An oscilloscope with a 200 MHz sample rate and 50 MHz bandwidth is sufficient. For extended time baselines, or variable sample rates, two or more oscilloscopes can be connected in series or parallel. A typical CRO record of a two pulser system is shown in Figure 5.

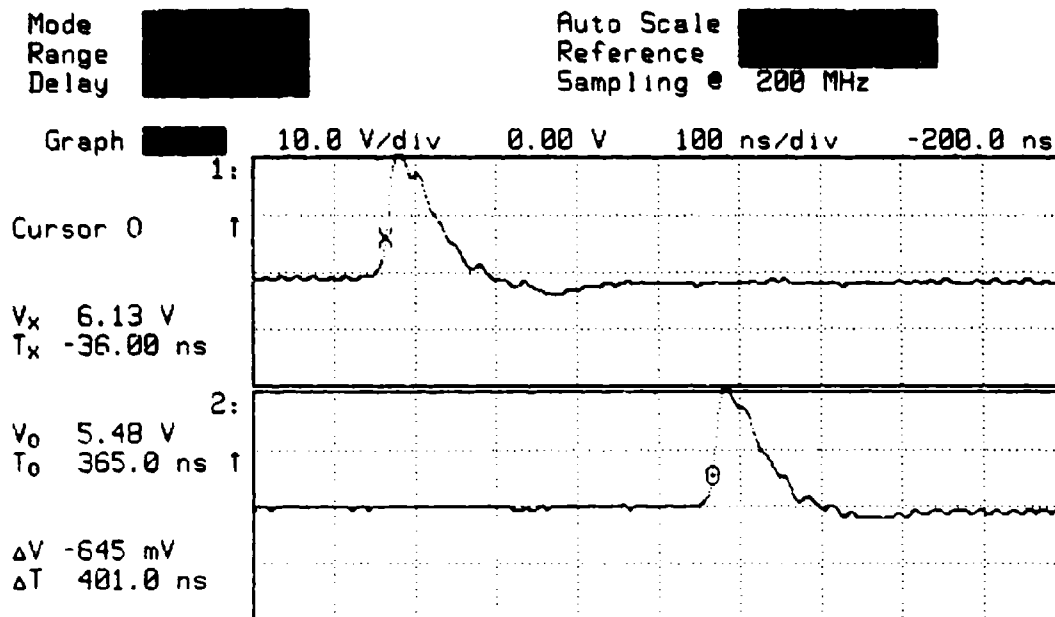


Figure 5: Flash X-ray pulser outputs as recorded on the digital oscilloscope.

2.5 X-ray Beam Alignment

The production of high quality radiographs requires that very tight control be maintained over factors that affect the exposure of the X-ray film. From the point of view of the beam alignment, it is necessary to collimate the beam as sharply as possible onto as small an area of film as necessary to allow the subject to be fully imaged. Failure to do this could result in cross exposures (Fig. 6(a)) or increased levels of scattered radiation (Fig. 6(b)). Both of these effects will result in a marked reduction in the contrast of the image.

In addition to reducing cross exposure and scattered radiation, it is important to know where the centred axis of the beam is in relation to the charge assembly. If this position is not known, distortions in the image can result in measurements that may be misleading. The flat surface of a cylindrical target block, for example, will be imaged as a curved surface if it does not lie in the same plane as the central axis of the beam. Furthermore, in order to obtain the best possible evenness of density over the image plane, the central axis of the beam should be perpendicular to that plane.

2.6 Remote Tubehead and Pulser Cradles

To allow maximum flexibility and stability in setting the beam alignment, we have designed a combination of remote tubehead or pulser cradles with lead collimator mounts that are easily fixed to the exterior wall of the firing chamber and provide a stable mount for the X-ray tubehead.

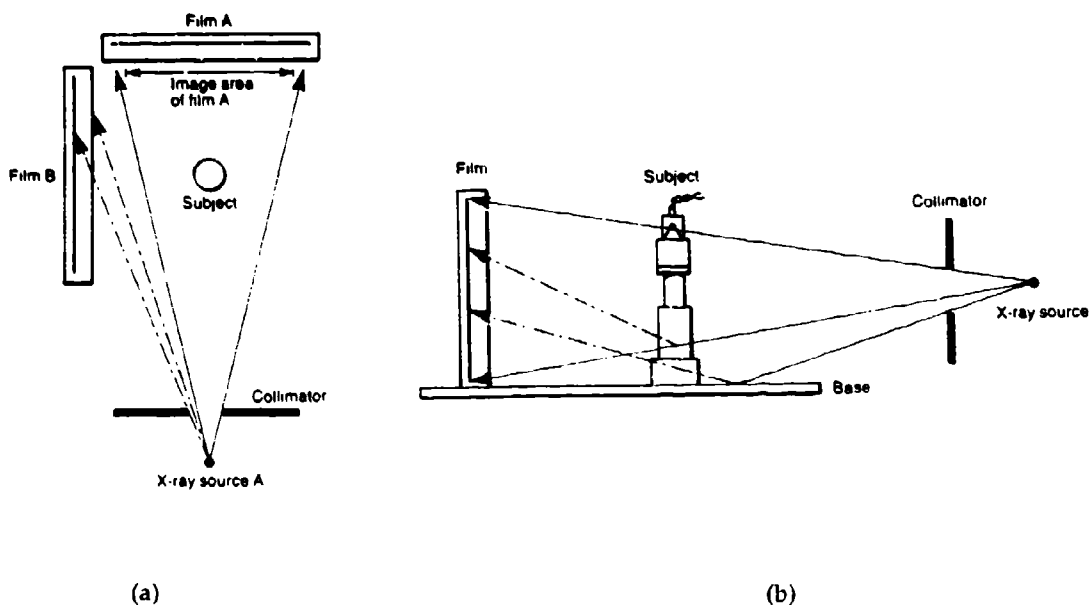


Figure 6: Reduction in contrast can be caused by (a) cross exposures or (b) scattered radiation.

The remote tubehead cradles are wheeled into position on a base that can be removed after the cradle assembly is fixed to the wall (Fig. 7(a)). Four base screws allow levelling of the cradle before it is fixed to the wall, and fine adjustments can be made in vertical and horizontal planes by screws under the cradle. Single or dual tube configurations can be fitted to the tubehead framework.

When a tube is located directly in the pulser body, the pulser is mounted directly onto the base frame (Fig. 7(b)). Adjustments to the orientation of the pulser can be made with adjustable supports on the base of the frame before it is fixed to the wall.

2.7 Lead Collimators

To reduce cross exposure and scattered radiation, lead collimators are built into the wall mounts to provide a stable aperture that may be easily varied when necessary. These collimators consist of 4 independent lead strips which are screw driven in or out to vary the size of a rectangular aperture aligned with the X-ray beam. They mount directly over the viewport on the external wall, in front of the tubehead or pulser at a distance of 300 mm from the tube window. When 300 kV X-rays are used, a lead thickness of 3 mm is sufficient to reduce the intensity of the beam by 75% in unwanted areas. 600 kV X-rays require the use of 10 mm of lead for a similar reduction.

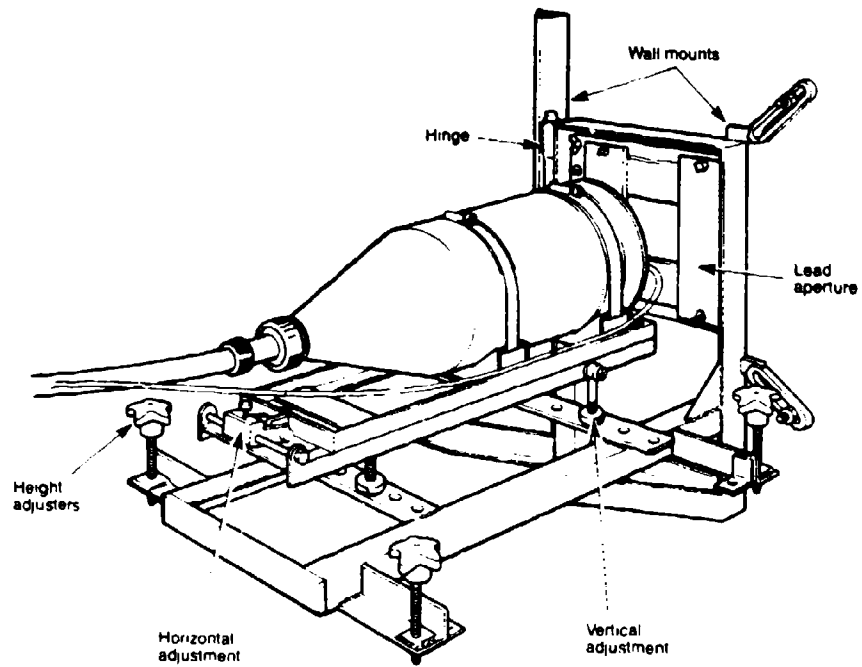


Figure 7(a): Remote head cradle.

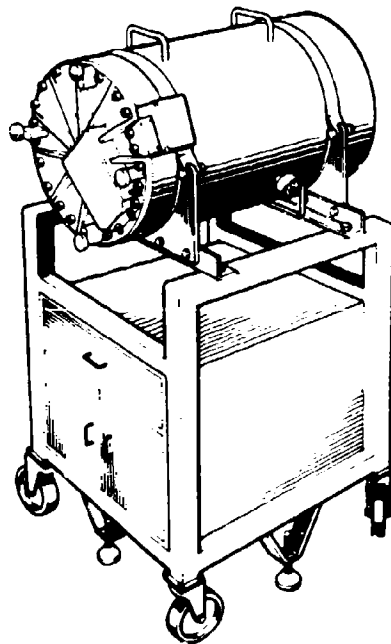


Figure 7(b): Pulsar mount.

2.8 Geometric Considerations

The X-ray tube has a source diameter of 4 mm which gives rise to an inherent unsharpness in the image as illustrated in Figure 8. This geometric blur reduces the accuracy of the measurements taken from the film and can be considerable in applications where it is not possible to position the film very close to the subject. For example, at a source to object distance (d_{so}) of 2400 mm and an object to film distance (d_{of}) of 350 mm, a 4 mm source size gives rise to a 0.6 mm penumbra. In general, the limiting factor that determines the minimum distance between the subject and the film cassette face in explosives instrumentation is the charge mass. If the cassette is too close the film will be affected by over-pressure or static discharge marks which can obscure the image.

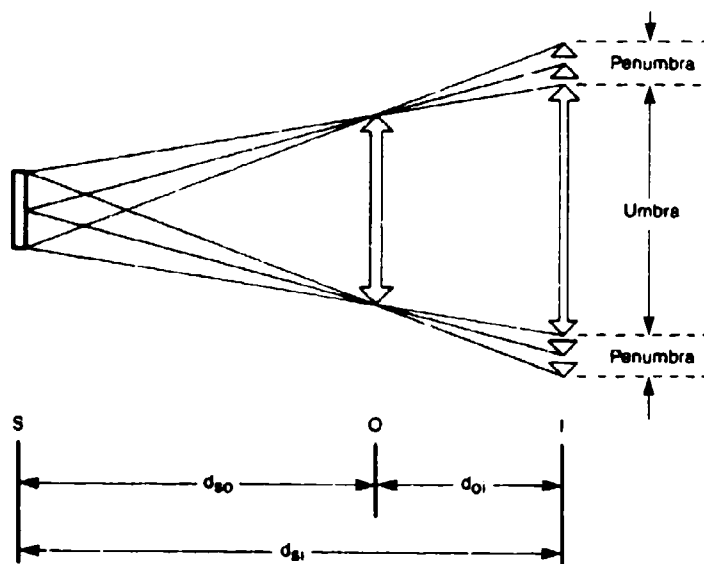


Figure 8: Geometric blur due to finite source size.

It is possible to reduce the penumbral area on the film by moving the X-ray source further away, but equipment limitations and X-ray intensity at the film plane mean this is not always an option. Experience is generally the best guide to achieving the most satisfactory compromise.

Similarly the distance between the lead aperture and the tube window should not be much less than 300 mm as the image of the aperture at the film plane should be as sharp as possible. At 300 mm, the unsharpness of the aperture edge (width of the penumbra) for a 4 mm source and a source to film distance of 2700 mm is 36 mm. A wide penumbra makes it more difficult to collimate the beam area.

2.9 Tube Protection

The X-ray tubes are usually located outside the firing chamber and expose the subject through the viewports in the firing chamber wall. These viewports are covered by 12 mm thick mild steel plates with a central port which is covered with aluminium and polycarbonate tiles (Fig. 9) and bolted to the inside wall of the firing chamber viewport. This method provides greater strength against blast and fragments than a full size window of aluminium or polycarbonate, and also reduces the cost of replacement of the aluminium and lexan due to fragment strikes in the beam area.

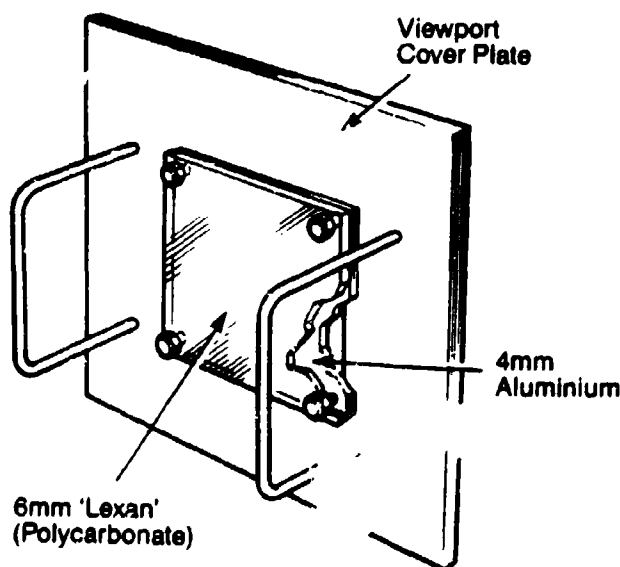


Figure 9: Aluminium and lexan covered viewports in steel window plates.

2.10 Film

The film package for flash X-ray (Fig. 10) consists of a pair of high speed rare earth intensifying screens in combination with medical X-ray film. The intensifying screens are necessary as the film emulsion is too slow to respond to the short duration pulses used in flash X-ray work. At present we use Agfa-Gevaert intensifying screens, typically MR600 or MR800, and Kodak XRP5 film. New screen and film combinations are evaluated periodically to ensure that we have the most appropriate combination.

Lead screens are also added to the film-screen package to reduce the amount of exposure due to low energy scattered X-rays. Typically 0.05 or 0.10 mm thick lead screens are taped to the front (tube side) of the film-screen package and 0.125 mm thick screens to the back. This increases the contrast in the image. The film-screen

package is enclosed in plastic light proof bags ready for loading into protective cassettes.

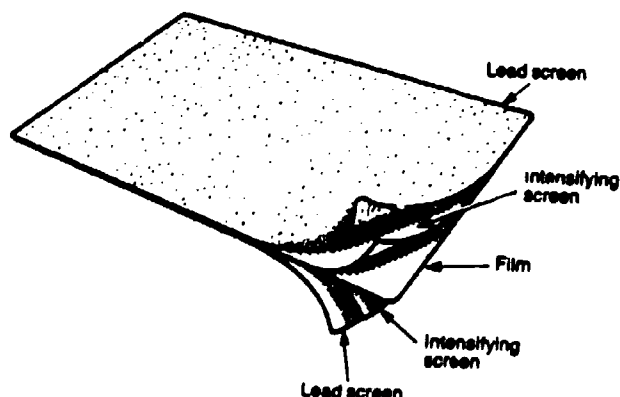


Figure 10: Film/screen combination.

2.11 Film Cassettes

Unlike the X-ray tubes which can be located outside the firing cell, the film package must be in close proximity to the charge assembly. This necessitates the use of robust protective cassettes in which to place the film assembly. Early design cassettes were made of aluminium which had several major disadvantages: they were heavy, absorbed and scattered part of the X-ray beam, were difficult to load and unload and their lifetime was limited; usually to less than 50 firings.

Polyethylene cassettes (Fig. 11) are now in use and have replaced the aluminium design in all but a few specialized applications. These plastic cassettes were designed at MRL and are lighter, attenuate and scatter the beam to a lesser degree, are simple to load and unload and have proved to be very robust. Typically they survive in excess of 50 firings with some designed for use with smaller charges remaining in service after more than 100 firings. They are easy to manufacture as the design is suitable for automatic machining techniques.

The interior of the cassettes is packed with a piece of low density compressible foam to ensure that the intensifying screens are in close contact with the film as any air gaps between the film and screen interface will result in an unsharp image.

2.12 Firing Geometry

Firings are generally carried out in a vertical direction unless specific considerations require a device to be fired horizontally. Vertical firing allows easier alignment as a plumb bob can be used to trace the anticipated projectile

trajectory. Vertical firing also makes multiple exposures simpler to arrange. Typically, up to four separate exposures can be made of an object with only a short (100 to 300 mm) distance of travel, and up to 10 exposures are possible for objects which travel over longer distances (500 to 2000 mm). In practice, however, although the system components for extended firings have been designed to allow 10 separate exposures, equipment restrictions (number of pulsers) have allowed us to test the concept with only three heads. An arrangement in which up to 10 separate exposures can be made per firing is shown in Figure 12. This drawing shows five film cassettes exposed by five remote heads. Note that the X-ray beam is fired under cassette number 1 and over number 5 to allow the maximum number of records in this configuration. Ten exposures are achieved by using two remote heads at each viewport (each independent) and timing the 10 heads in an appropriate sequence, exposing half of each film, one at a time.

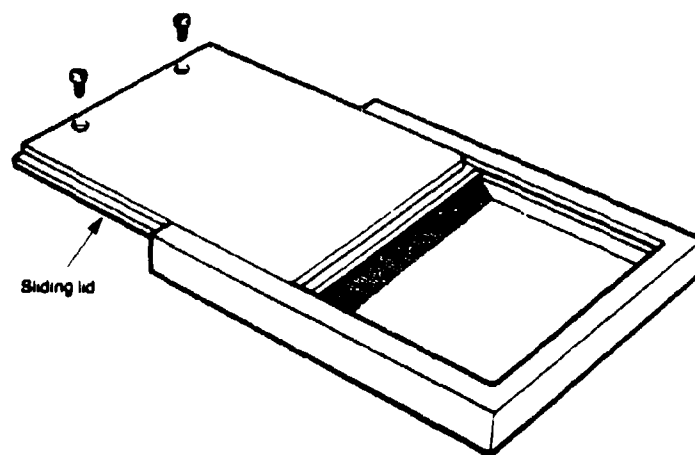


Figure 11: Polyethylene film cassettes.

2.13 Film Cassette Protection

The amount of shielding used to protect the plastic film cassettes is no more than that required for similar aluminium cassettes. Whenever possible, fragment shields (usually 9 mm thick walled mild steel rings) are placed around any fragmenting part of the charge. This then reduces the amount of shielding necessary to protect the film cassette, however this is only possible when the area of interest in the subject is not obscured by the fragment ring.

We have found that a combination of 6 mm thick lexan and 4 mm thick aluminium (type 5083) sheets provides adequate protection in most cases, and the cassettes can often be used with no additional protection. Selection of the appropriate cassette size and construction aids protection, and variations on the standard design of cassettes discussed above are occasionally used.

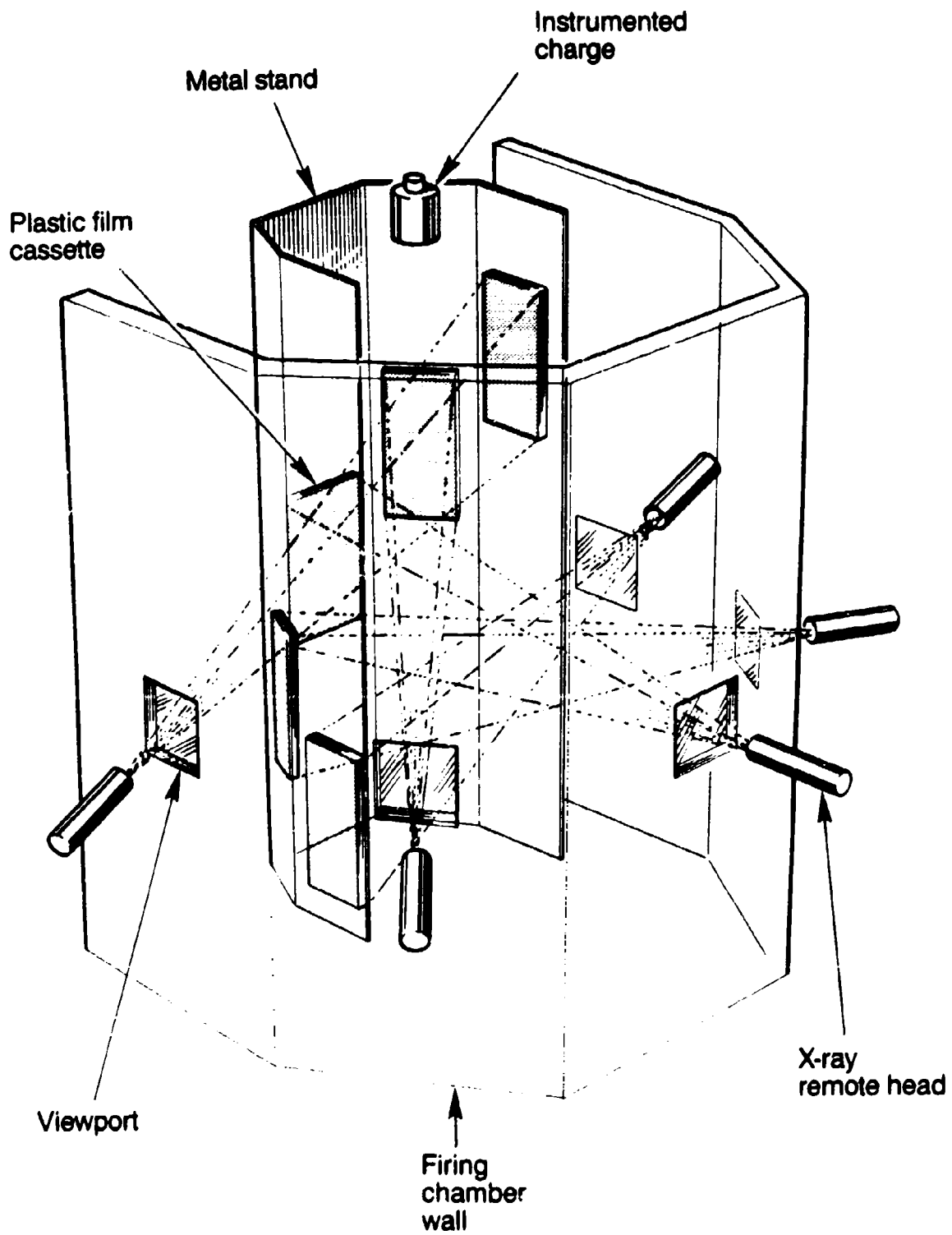


Figure 12: Experimental flash X-ray arrangement for five image recording.

A typical arrangement of charge and film cassette is shown in Figure 13. The distance between the front face of the cassette and the charge axis depends on the size and type of charge, but is usually of the order of 300 mm.

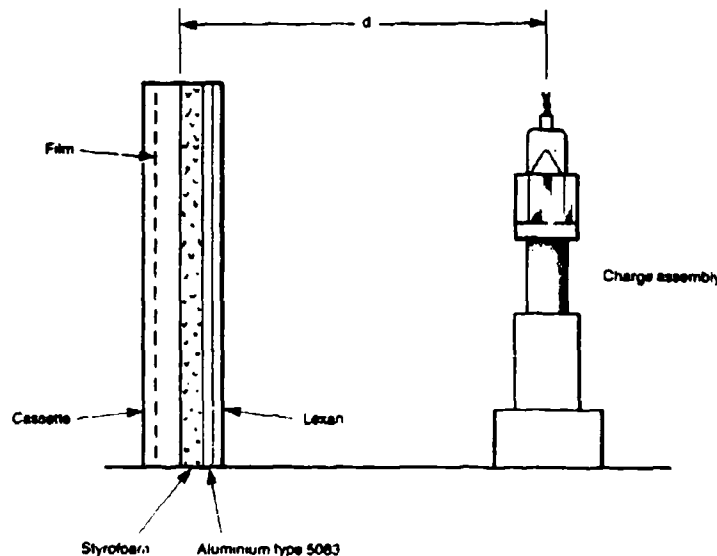


Figure 13: Charge, film cassette and protection screen arrangement.

2.14 Film Exposure

Exposure charts plotting energy of X-rays versus film density contrast were established for various film/screen combinations using a radiographic step wedge principle. These charts, when used in conjunction with controlled film processing conditions, provide an exposure guide for imaging subjects with a suitable density range. Assessment of the image quality of radiographs is achieved using wire type image quality indicators of the type DIN 54109. These indicators provide a means of measuring geometric and inherent unsharpness present in the image.

2.15 Film Processing

An automatic film processing machine was designed and installed to provide predictable and repeatable processing of exposed radiographs. The system is based on a dip-and-dunk principle commonly used in film photofinishing laboratories. It allows a wide range of processing conditions with independent control over time, temperature and agitation, and will process up to 20 large sheets of film per hour. The optimum processing conditions found for flash radiographs using Kodak XRP 5 film and Agfa MR 600 was 5 min at 25°C with nitrogen agitation for 5 s every 30 s. Film was processed to achieve an average

contrast in the vicinity of 2.2. Kodak process control monitoring strips are used to monitor processing solution activity and provide a guide for maintaining consistent processing solution replenishment.

2.16 Printing of Flash Radiographs

A technique has been developed for the improved reproduction of flash radiographs. The technique uses an application of the contrast masking method sometimes used to adjust the density range of photographs prior to printing and is well documented in many photographic texts. A brief explanation follows.

Many flash radiographs show detail with low contrast in an otherwise high quality image. Typically this is due to minor changes in density of the subject matter. In order to improve the quality of the image it is necessary to increase the contrast of the small range of densities corresponding to the area of interest. The overall contrast of the image must remain essentially the same to retain the general image quality.

An unsharp, low density complimentary mask is first made from the radiograph. This is achieved by contact printing the radiograph onto Gevamask P135P masking film. A sheet of clear (fixed, unexposed) X-ray film is placed between the radiograph and the masking film, and a wide enlarger lens aperture is used to ensure the mask is relatively unsharp. The density of the mask is adjusted to give the best results. Register pins are used to ensure that the images are accurately aligned throughout the process. This is a somewhat laborious part of the process that has to be determined independently for each series of images.

Once a suitable mask has been prepared the radiograph and the mask are sandwiched in register and copied on a light box onto Ilford Ortho 5" x 4" sheet film. This produces a negative that can be printed using conventional techniques to yield a print of suitable contrast and density for the form of reproduction to be used. Burning and dodging techniques can be used to produce a pleasing image, but are not required to increase the contrast of the detail enhanced by the masking technique.

A number of factors affect the degree of enhancement achieved with this technique. By sandwiching the mask with the radiograph the overall contrast of the image is reduced. As the mask is unsharp it has little or no effect on the fine detail areas of the image. By photographically copying the image and increasing the contrast to a normal level again, an increase of the contrast of the fine detail relative to the overall contrast is achieved. The density, sharpness and contrast of the mask, and the density and contrast of the copy negative all contribute to the overall effect. By manipulating these variables a wide range of effects can be achieved.

3. Applications

3.1 Shaped Charge Liner Collapse

The performance of 1 and 2-D hydrocodes to predict behaviour of the functioning of a shaped charge device was assessed using flash radiography. Of particular interest was the determination of the parameters of the collapse mechanism of the conical copper liner driven by the detonating explosive [2].

Two orthogonal views were used to obtain the images, and X-ray energy 600 keV (maximum for our system) was required to highlight detail of the jet formation in the interior of the copper cone. Maximum contrast over a small area obscured by detonation products and case fragments was achieved by ensuring exposures and processing conditions were at optimum levels. This involved the tests mentioned above along with several static firings of an object simulating the functioning charge at various stages. The minimum object to film distance before damage to the films occurred was also determined. This allowed the sharpest image to be obtained by minimizing unsharpness due to geometric factors.

Typical results are presented in Figure 14 which shows the collapsing copper liner at times of 7.0 μ s, 10.2 μ s and 18.6 μ s. The inside surface of the liner is visible, as is the emergence of the jet tip which is produced from this surface. The clarity of the images allowed measurements of the liner collapse angle, jet tip and slug tip displacements, case expansion velocity etc. [2]. Details of image analysis of these results can be found in reference 3.

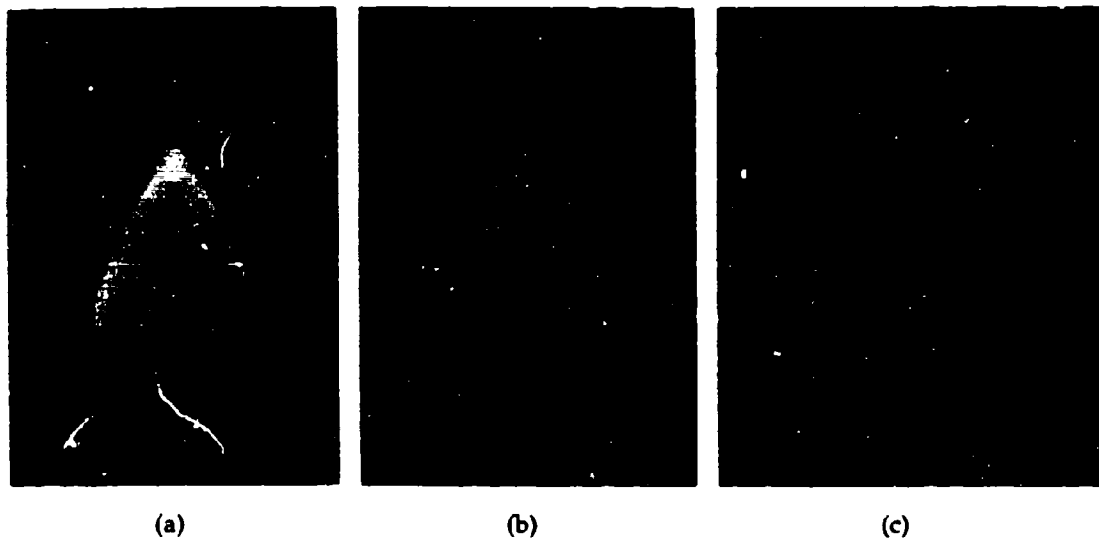


Figure 14: Flash radiographs of 38 mm MRL shaped charge collapse. Times after detonator functioning (a) 7.0 μ s, (b) 10.2 μ s and (c) 13.9 μ s.

3.2 Jet Initiation of Explosives

The interaction of a 1.5 mm diameter copper shaped charge jet with a Composition B acceptor was investigated using MRL flash X-ray techniques [4]. The processes occurring with both bare and covered acceptor configurations were determined directly from analysis of the flash radiographs. It was found that the presence of a precursor wave in front of the jet penetrating the cover can act as a desensitizing mechanism in the explosive. This precursor wave is dissipated by the air gap between the standoff barrier and the bare explosive; in the absence of the desensitizing mechanism, prompt initiation of the acceptor charge may occur.

In this investigation it was necessary to have high contrast in areas where small changes in explosive density occurred, i.e. in the area of the jet tip and precursor wave. This objective required that very tight alignment of the X-ray beam had to be maintained to reduce scatter to a minimum and eliminate any cross exposures of the films. The preliminary exposure tests discussed above were carried out in detail.

A typical result for the covered acceptor configuration is shown in Figure 15(a). The jet and precursor bow wave can be clearly seen, along with the cavitation in the explosive caused by the penetration of the jet. Note the expansion of the top section of the explosive. The sides of the charge are still well defined. This is a consistent observation with a charge that is expanding from the radial component of the bow wave caused by the penetrating jet.

A flash radiograph showing the detonation resulting from this type of reaction is shown in Figure 15(b). Note that the detonation front is much more pronounced than the precursor bow wave, and the expanding sides of the explosive are not sharp. This observation is typical of a detonation. Note also that a detonation front can be seen travelling backwards through the explosive. This is a general observation when this type of initiation occurs after a finite run.

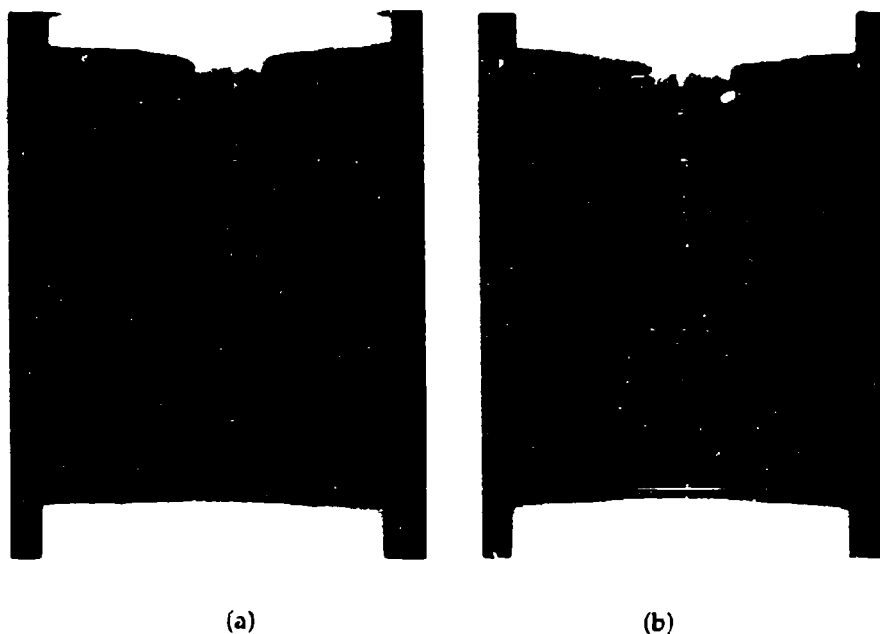


Figure 15: (a) Covered Composition B acceptor prior to detonation, (b) after initiation of detonation.

Explosive desensitizing by a precursor bow wave in the explosive is shown in Figure 16 with a split charge arrangement. The upper explosive acceptor is in contact with a steel cover, and separated from the lower acceptor by an air gap. Figure 16(a) shows the penetration of the upper acceptor by the jet without initiating a detonation. In 16(b) the jet has crossed the air gap and initiated the lower acceptor on impact. The strong detonation front and unsharp edges are again visible in the lower acceptor, indicating detonation, while cratering and expansion of the top acceptor occur as before.

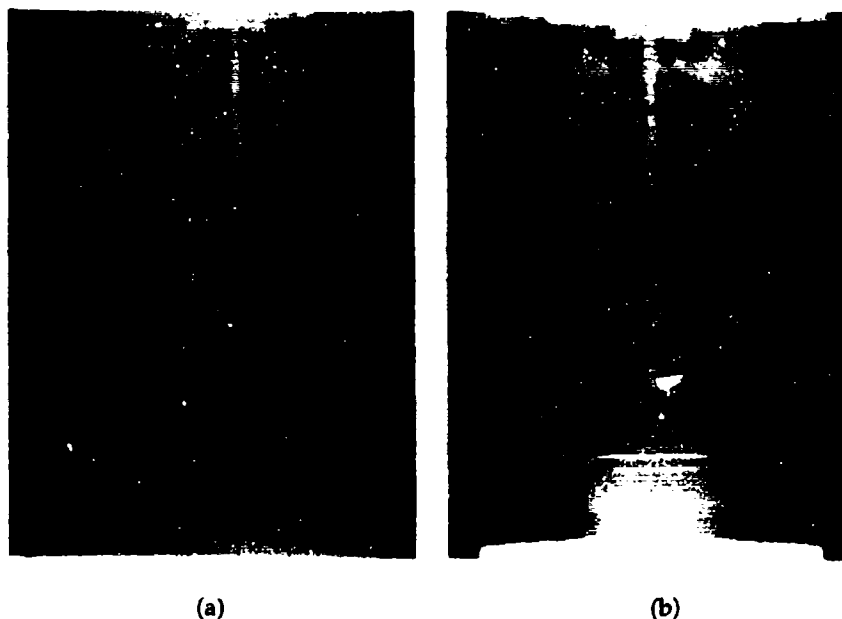


Figure 16: Desensitization of Composition B by a precursor wave.

3.3 Small Diameter Jet Initiation

One of the factors affecting the reaction process in jet initiation is the diameter of the jet relative to the critical detonation diameter of the explosive acceptor. As discussed in the previous section, the initiation of bare Composition B by a 1.5 mm diameter jet occurs near the surface of the acceptor. If initiation does not occur near the surface, the acceptor then fails to detonate. When a jet of diameter 0.75 mm is fired into an acceptor of Composition H-6, initiation can occur well below the surface [5] and this is attributed to the relative effect of the jet diameter to the explosive's critical detonation diameter.

Flash radiographs of this process are shown in Figure 17. As in the previous example, it was again necessary to maximize contrast, but in this case it was also necessary to reduce the unsharpness in the image arising from geometric blur because of the small diameter of the jet. This was accomplished by reducing the object to film distance as much as possible without introducing pressure and static marks on the films due to blast effects. To allow this reduction, the explosive mass was kept as

low as possible by removing any excess acceptor charge and smaller, more rigid cassettes, were used to protect the films.

The radiographs show penetration of the acceptor by the copper jet prior to, and just after the transition to detonation. Note that the detonation and retonation fronts in Figure 17(b) form a closed surface within the acceptor as the reaction fronts move away from the point of initiation.

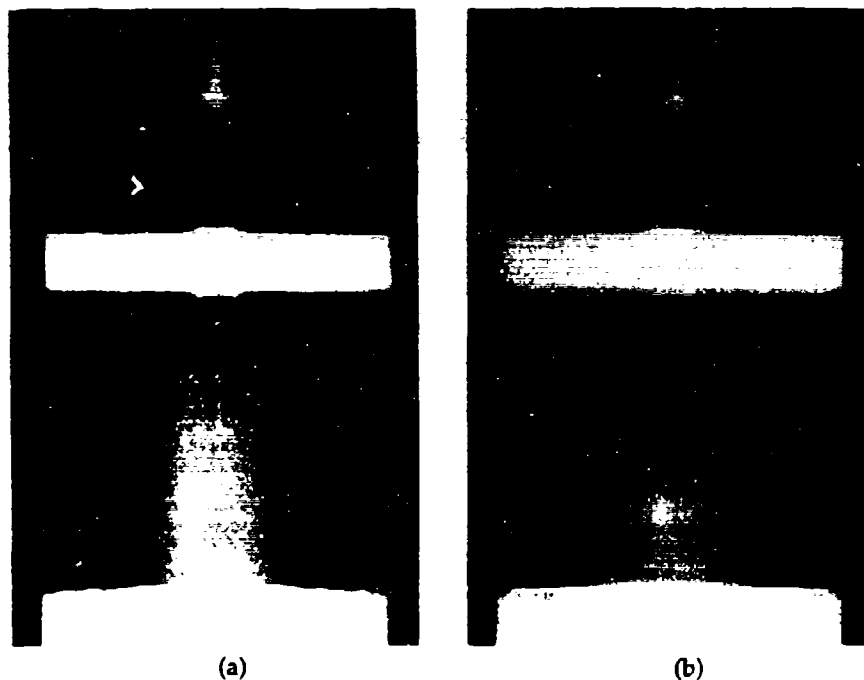


Figure 17: Initiation of Composition B by a 0.75 mm diameter copper shaped charge jet (a) prior to detonation, (b) just after the transition to detonation.

3.4 Jet Particulation

The particulation of a shaped charge jet has been well documented by many authors. MRL has investigated the properties of a particulated jet to determine the possibility of measuring the position of a virtual origin [6] and to quantify the effects of explosive head height on the velocity gradient and jet performance [7]. The virtual origin approximation assumes that all the jet mass particles originate at one point in space and time [8].

The experimental arrangement for the measurement of individual particle velocities in a particulated jet was shown earlier in Figure 12. The total distance travelled by the jet while remaining in the field of view of the X-ray beam is approximately 1750 mm and each exposure is made on a separate film. This method of exposure was chosen over a method in which the jet is fired horizontally and successive exposures made on a single film to allow (i) a greater number of exposures, and (ii) a higher quality image. This method also allows any deviations in the jet path due to waver to be detected as the images are recorded by orthogonal pairs.

An example of a particulated jet at times of 106 μ s, 156 μ s and 202 μ s after initiation of the shaped charge detonator is shown in Figure 18. The separation of the particles as time increases is evident, consistent with a velocity gradient along the jet length.



(a)



(b)



(c)

Figure 18: Particulated copper shaped charge jet at (a) 106 μ s, (b) 156 μ s and (c) 202 μ s.

It is important to minimize any errors in the measurement of the particle positions as even very slight variations give rise to noticeable changes in the particle velocities, as the distances travelled between successive exposures is generally small. The use of orthogonal views and appropriate fiducial points can assist in the minimization of these errors.

3.5 Initiation by Spall

It was observed in oblique firings of shaped charge jets through metal plates, that spalling from the underside of a target occurred in a direction perpendicular to the surface of the target, and not parallel to the direction of the jet. This perpendicular spalling is shown in Figure 19, in which the jet was fired at two thin metal plates separated by an air gap. The central axis of the X-ray beam was aligned with the centre of the air gap to allow the imaging of the two bottom surfaces with as little distortion as possible.

In order to allow more than one exposure, the plates were orientated horizontally and the jet fired at an obliquity of 60° . When this is done however, the jet is not moving parallel to the film plane, and any calculation of jet tip velocity will need to take into account the change in magnification occurring because of this motion. In addition, measurements of the jet tip position must take into account foreshortening of the horizontal component of motion due to this geometry. This also applies to the measurement of the jet angle recorded on the film. Careful choice of fiducial points can simplify these considerations.

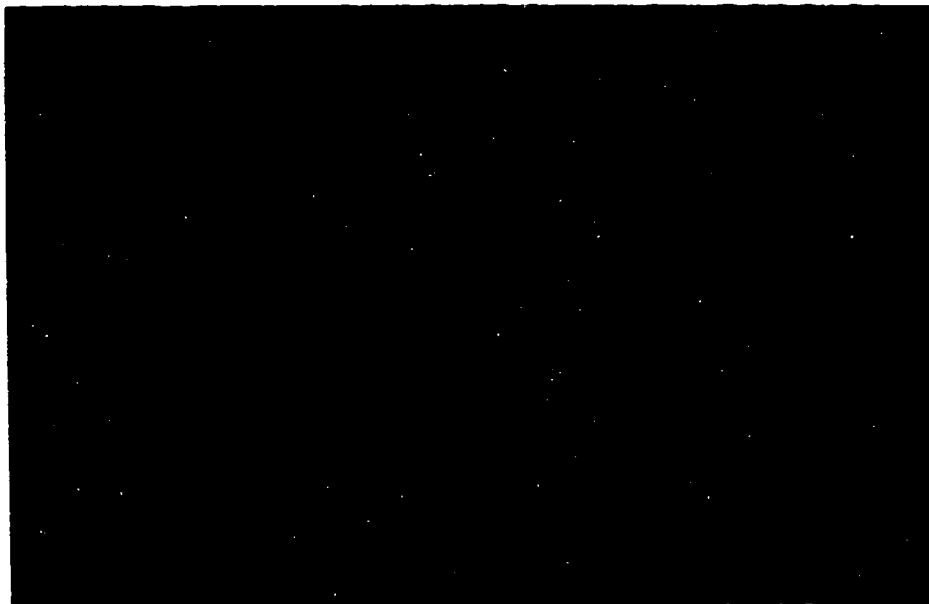


Figure 19: Spall generated by an oblique jet.

This property of spalling from the underside of a metal plate allowed the separation of the spall and jet after penetration. We were able to use this observation to test a hypothesis by Held [9] in which he considered that the initiation of bare Composition B by a shaped charge jet included the spalling of metal from the standoff barrier onto the surface of the acceptor, and not due solely to jet impact.

The experimental arrangement for this can be seen in the flash radiographs of Figure 20. Here the jet is fired through a thin cover (a) and aimed to miss the acceptor charge while the spall impacts the acceptor surface. With the thin plate, a large amount of spall is generated. In a separate firing, the jet is fired through a much thicker barrier (determined to produce a jet velocity marginally above the critical value) and aimed to hit an acceptor but without spall (b). Although the acceptor in (a) is seen to be impacted by a large amount of spall it did not detonate, while the acceptor in (b) is seen to be detonating very promptly due to impact by the jet alone. This study is described in more detail in reference [10], and supported the initial proposal by Chick and Hatt [2] that it is the jet and not the associated spall that causes initiation in the bare configuration.

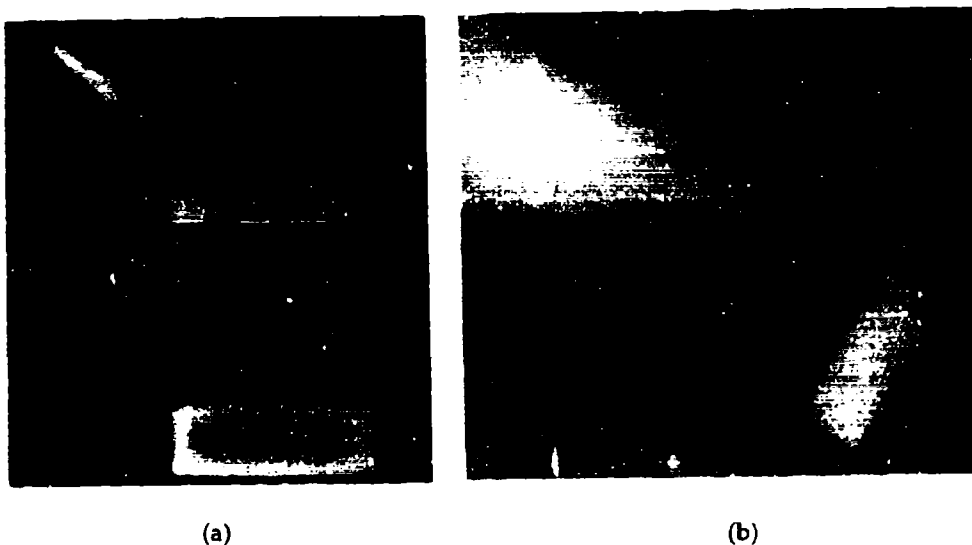


Figure 20: (a) Failure of spall to initiate Composition B; (b) initiation of Composition B by jet alone (no spall).

4. Conclusions

The production of high quality flash radiographic images of explosive phenomena is achieved by optimising the many variables associated with the imaging processes. We have found that it is necessary to consider aspects from the recording geometry used to the final stages of film processing, and each object will generally require different considerations along the way. Of particular importance are:

- preliminary, static exposure tests to assess requirements
- object and film geometry recording
- minimizing scattered low energy radiation and cross exposures
- film processing conditions
- enhancement of results for analysis, display and publication

In some cases, the subject can be subdued by reducing the explosive mass or fragmenting components thereby making higher quality images easier to obtain.

5. Acknowledgements

This report represents a summary of some applications and techniques that have been developed since flash X-ray was first used here as a diagnostic tool. In respect of this, we would like to highlight the efforts of David Hatt and Ian Macintyre for their early work in these areas, and extend our thanks to Robert Irvine, Fred Whitty and the members of Explosives Ordnance Division staff who have been involved in flash X-ray programs at MRL.

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ABSTRACT

This report describes multiple, flash radiographic techniques developed in an investigation aimed at understanding and predicting the processes which occur when a hypervelocity projectile interacts with explosive filled ordnance. Hypervelocity projectiles were generated by shaped charges and characterized by multiple flash radiography. Explosive/metal target assemblies were designed to be representative of various aspects of explosive filled ordnance or components.

The techniques have been used to study the projectile impact on bare explosive, penetration through covers into explosive, the supersonic projectile penetration of the explosive and the evolving structure of the bow wave shock that forms several millimetres in front of the projectile tip, the onset and progress of detonation both forward and backward in the explosive and the relative contribution of spall and jets in behind-the-plate initiation of explosives.